FINAL REPORT

PROJECT A-1207

FEASIBILITY STUDY OF REUSABLE SHIPPING CONTAINER

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[redacted]

"Feasibility Study of Reusable Shipping Container"

I. SUMMARY

An extensive study of materials for use in reusable shipping containers has been made. All of the major and a very large number of the smaller companies involved in fabrication of plastic components, shipping containers, and materials for use in fabricating shipping containers were contacted.

Without exception, these companies said that an all plastic container was not feasible if the containers were to be stacked. If the requirement for stacking were removed several different approaches appear feasible and economically practical.

Our calculations confirmed the advice given by the plastic companies. Plastic creep to which all plastics are subject causes the containers to slowly deform while under load as a function of time.* The longer a load is left on a plastic object the greater is the deformation experienced by the plastic. In column type loads as in the walls of a container with a larger load applied to the top, plastic creep becomes progressively worse with time because, as the walls begin to bow, the bending stresses increase. This causes the wall to bow more rapidly and eventually the wall reaches a bowed condition such that it is no longer able to support the load. Collapse then results.

A study of a fiberglas coated plywood container was also initiated and had progressed sufficiently far to indicate that a container meeting the stipulated requirements could probably be designed and built. This work was stopped when Mr. Harry S. Hart of the Weathers Brothers Van Lines,

*See Appendix I.

Inc., advised Georgia Tech that this approach was unsatisfactory to Weathers Brothers because of the weight of the container and because of difficulty maintaining adequate seals at panel joints.

Six different all plastic concepts were studied to determine feasibility should the requirement for stacking be removed. This study showed several container construction materials and techniques which are feasible and practical. Two of these were recommended for prototype construction.

Due to the nature of the results from this study, no design was finalized, and no detail drawings of any design are included as a part of this study. It will be necessary to work out design details during a prototype study due to the diverse nature of the materials and methods of fabrication.

II. INTRODUCTION

A preliminary study of the concept of a reusable shipping container for use in the shipment of household goods showed considerable merit in the basic concept.

It was pointed out in this initial study that the claims of the Poly-Con Industries of Detroit, Michigan, appeared extravagant and that it was felt that their cost claims were certainly subject to question. A subsequent conversation with Mr. Harry S. Hart of Weathers Brothers revealed that Poly-Con indeed could not fabricate the containers at their initial estimated cost. Mr. Hart was advised by Poly-Con that a new fabrication technique would permit fabrication at a lower cost.

The previous Poly-Con container could not be stacked while loaded because of container shape. Mr. Hart was advised that the design could be modified to permit stacking. Although it is possible that Poly-Con can make the wall section so massive that stresses will be sufficiently low to permit stacking, it is doubtful that the container would be economically practical. Based on a Poly-Con container section which I have examined, I would say their technology is not ahead of other plastic processors.

My initial study indicated that price would be the limiting factor, but this has not turned out to be the case. It has been determined that containers can be fabricated a minimum of six different ways at a cost of approximately $400 each. A more in-depth study including a stress analysis of an initial design revealed that wall stresses were sufficiently high when the containers were stacked, that plastic creep became the limiting factor. Plastic creep is deformation which is both load and time dependent, i.e., the longer a load is left on a part, the greater is the deformation observed. This is especially bothersome in areas, such as walls, which are very sensitive to deformation.

As was pointed out in my initial investigation, the idea of a reusable shipping container shows so much promise that despite pessimism in respect to meeting all of the goals of the container further investigation certainly appeared desirable.

Initially it was expected that the project could be completed within eight (8) to ten (10) weeks. Unfortunately, the inability to meet one of the requirements, that of stacking loaded containers three high, has caused repeated changes in direction to try to get around this problem. Each change in direction required re-contacts with some companies and new contacts with others. All of the companies contacted still have not been heard from, but enough replies have been received to arrive at several firm conclusions and recommendations.

III. PROGRAM

Our initial approach was a brief literature survey to determine which companies are involved in plastic production or in the fabrication of large plastic components. From the survey a selection was made of the most promising companies, and letters were written outlining the container requirements and requesting technical assistance should the company feel the container was within the state of the art.

Approximately half of the companies contacted sent brief literature describing what they were presently making and stating that they were not interested in undertaking a program such as would be required to develop the container. Several of these replies stated they were not equipped to undertake such a program but suggested that we contact a specific company or companies. This resulted in additional letters or in the more promising cases telephone calls followed by letters.

Of the initial inquiries approximately forty (40) per cent sent technical salesmen to talk directly with us. Almost without exception the salesmen expressed enthusiasm for the idea and stated the container was well within the state of the art of their company and that they could meet all of the objectives including cost and stacking.

This response would have generated considerable optimism on our part had we not begun to get results from a stress analysis of a preliminary design made at Tech. This analysis indicated that the container was technically feasible except when stacked. The analysis indicated that when stacked the lower containers would experience plastic creept and eventually fail. Even so, there was still some optimism because of the hope that experts in the plastic area might have techniques to design around the problem.

The optimism was short-lived though because conversations with the engineers at the factories and research centers soon confirmed our calculation. Without exception every company contacted stated that if the containers must be stacked plastics were not practical and that we should consider fiberglas coated plywood in a metal framework.

One company with an active group that has been involved in container technology for over two years gave us the names of eight companies involved in glass coated plywood fabrication and suggested that one of these should provide the materials for a container meeting the requirements we stipulated.

All eight of these companies were contacted, and positive replies were received from two companies. The other six either were not interested in the problem or were incapable of helping.

A container was designed and stress calculations initiated based on fiberglas coated plywood. Work had progressed sufficiently far to indicate that a satisfactory container probably could be built. At this time a visit from Mr. Harry S. Hart revealed that Weathers Brothers was not interested in pursuing a coated plywood container any further. He stated that their experience with plywood containers indicated that adequate sealing was very difficult to obtain, and the high weight of a plywood container added to their dissatisfaction. Work was stopped on this design immediately.

At this point the program was nearing completion, and the only container capable of being stacked had been eliminated. It was decided to re-contact the plastic companies and request assistance in determining feasible methods of fabricating all plastic containers which would meet all requirements except stacking. The idea was that the containers could be stacked if auxiliary means were used to support the weight of the upper containers. Time had become very limited at this point so the approach had to be very brief; but the more the idea was considered, the more attractive it appeared. The idea of using shelves or metal framework to support the upper container weight eliminated one of the problems that had been bothersome even with the fiberglas coated plywood. A potentially dangerous tipping situation existed with free standing containers stacked twenty-five feet (25') high and being only five feet (5') deep. A minor impact with a forklift truck could have caused one or both of the upper containers to fall. This situation does not exist with a load-supporting framework on which the containers are positioned.

IV. CONCLUSIONS

Due to the short time that was spent on the non-stacked concept, data is somewhat limited; but enough information has been obtained on the overall program to reach the following conclusions:

1. Unsupported plastic containers which can be stacked three high are not within the present economically feasible state of the art.
2. Fiberglas coated plywood containers which can be stacked are economically feasible. The containers are heavy, probably over 600 pounds each, and may prove difficult to seal. It is felt that the sealing problem can be solved with a little experimentation.
3. An all plastic container which can be stacked probably can be developed, but it would likely take a rather extensive

and probably expensive development program to arrive at a satisfactory container. There is not enough information to even estimate the probable unit cost after the development program.

4. There are many satisfactory ways to fabricate an all plastic container that will meet all of the container requirements except the capability of being stacked. Several of the most promising methods are described below:

   A.) ABS Plastic Sheet Laminate with a Polyurethane Foam Core. This container can be fabricated from flat ABS sheet welded into two concentric boxes with a polyurethane foam core cast into the space between the boxes. It can also be fabricated from flat sheets of ABS which already have the foam in place. Both methods require only simple jigs and fixtures and are adaptable to prototype construction. A container weighing less than 400 pounds and costing less than $400 appears feasible. No company is presently making this composite.

   B.) Polyester-Fiberglas Composite with a Urethane Foam Core. These sheets are commercially available and can be joined either by bonding or by bolting into aluminum extrusions and sealed with a sealant like butyl rubber. The bonded box would not require a sealant. This concept requires simple jigs and fixtures and is adaptable to prototype construction.

Container weight would be over 500 pounds, and it would cost slightly over $400 each.

C.) Cast ABS Foam. This process consists of casting the desired container in a relatively simple mold from a foam ABS resin and then heating the mold to fuse the resin. At the present time a container meeting all of the requirements except stacking is practical. Unfortunately the container would weigh over 600 pounds. Lighter weight ABS foam is expected soon, but it is too early to estimate cost, weight or mechanical properties. If this system continues to improve it may well prove to be the most desirable container.

D.) Cast Urethane Foam with Spray Polyester-Glass Surfaces. This container would require a urethane foam casting mold more complex than the simple jigs and fixtures used with the containers described above. This method while attractive from a cost standpoint would result in a container considerably less sophisticated and less attractive than some of the other methods. The container would weigh over 500 pounds and cost approximately $400 depending upon the care taken in fabricating the box. This method is not ideally suited for prototype work.

E.) Dynakore Composite. This material consists of ABS surface sheets with a number of varying density polyethylene core sheets. The container would be fabricated from flat sheets welded at the interfaces with an epoxy or urethane filler used to stiffen the joint. It appears that a container weighing less than 425 pounds and costing less than $400 can be fabricated. Availability of the material is limited at present, but this should improve within the next year. The material is suited to fabrication of prototypes.

F.) Rotationally Molded Box Using Composite Consisting of Urethane Foam Core and Either of Several Surface Sheets. This method of fabrication would probably be the ideal method for production because it is rapid, reliable and would result in the least expensive and most uniform container. It is impractical for small quantities due to mold cost but would result in lowest unit cost in large quantities. Unit cost would vary widely depending upon materials used in fabrication. In this process a large mold is mounted in a fixture which can spin the mold about any of several axes. The mold is spun and the initial surface sheet material is injected into the cavity. Centrifugal action spreads the material evenly over all walls. The core material is then injected followed by the inner skin. This method is not adaptable to prototype construction.

G.) Poly-Con Industries Fiberglas-Urethane Container. This container is included here solely because of the previous interest by the sponsor and because it provides an opportunity to compare probable properties. The method of fabrication is unknown, but the container once fabricated should have properties very similar to containers B and D.

Table I provides a summary of the pertinent properties of the various containers. It allows comparisons which should allow the sponsor to select which container is the most appealing. The fiberglas coated plywood container has been omitted because of the sponsor's expressed dislike for this type construction.

V. RECOMMENDATIONS

In light of the present state of the art, it is impossible to recommend a particular container material and construction and say with complete confidence that it will be completely satisfactory.

It is therefore recommended that a program be initiated that will result in eight prototypes, four each of two types of construction. It is recommended that these eight containers be put into service in a controlled use such that all containers will see the same environment. It is important that the specific use be controlled such that the containers are continuously in service and are not stored away in a warehouse for any appreciable length of time. If it is possible, four of the Poly-Con Industries containers should also be tested.

Carefully documented records of these eight to twelve containers should be quite conclusive within six months and certainly within one year.

It is recommended that the ABS Sheet-Urethane Core Container (A) and the Dynakore Composite Container (E) be the two types tested. All data available indicate these two containers should have the best performance.

TABLE I

COMPARISON OF PRACTICAL SHIPPING CONTAINER CONSTRUCTION

No.	Description	Estimated Weight--lbs.(4)	Estimated Cost--$ (5)	Adaptable To Prototype Construction	Impact Resistance	Repairability	Resistance To Weather	Fabrication Method
A.)	ABS Face Sheets with Urethane Foam Core	400	Less than $400	Yes	Good	Good	Good	Welded and then foamed
B.)	Polyester-Fiberglas Sheets with Urethane Foam Core	More than 500	More than $400	Yes	Fair	Good	Fair to Good	Bonded or bolted and then foamed
C.)	Cast ABS Foam	More than 650 (1)	Less than $375	Yes	Fair	Fair	Good	Cast
D.)	Cast Urethane Foam Sprayed Polyester-Fiberglas	More than 500	$400	Yes	Fair	Fair	Good	Cast and then sprayed and rolled
E.)	Dynakore Composite (2)	425	Less than $400	Yes	Good to Very Good	Fair	Good	Welded and foam sealed
F.)	Rotationally Molded Composite	Depends upon Materials	Less than $400 in large quantities	No	Depends upon Materials		Good	Rotationally molded
G.)	Poly-Con Industries Composite Container	More than 700 (3)	More than $500	?	Fair to Good	Good	Good	?

(1) Lighter material should be available in the near future.
(2) Availability of this material presently questionable, but should be available soon.
(3) This weight estimate made from weighed section of Poly-Con container wall.
(4) See Appendix III.
(5) See Appendix II.

APPENDIX I

APPENDIX I

STRESS ANALYSIS OF PLASTIC CONTAINERS

Plastics, like other materials, deform under load. The amount of deformation depends upon the unit stress, the modulus of elasticity of the material, the geometry of the load-bearing part, the time of load application, the temperature and the environment. Part of the deformation will be reversible, that is, it will be recovered upon removal of the load. This portion is called elastic deformation. The remainder will not be recovered upon removal of the load. This portion is called plastic deformation.

Some materials under some conditions, for example, certain steels at room temperature in air, exhibit no easily measured plastic deformation at stresses below the elastic limit. Some other materials, for example, lead, exhibit considerable plastic deformation even at low loads and low temperatures.

Plastics, sharing their elastic nature with steel and their plastic nature with lead, are termed "viscoelastic." A knowledge of both elastic and plastic response under various conditions is necessary to a full description of their load-bearing behavior.

Strength is commonly taken to mean the ability of a material or structure to withstand load. Published data is usually taken from samples which were carefully tested under controlled conditions and at a relatively fast rate. Comparison of these published data with curves for samples tested over long periods of time reveal that most materials have a strength of approximately one-fifth the short-time strength when tested five (5) years. A value of one-fifth was applied to all plastic materials considered in this investigation because long-time data were not available for the particular combinations considered for the containers.

Stiffness or modulus is a measure of the ability of a material or structure to resist deformation. Again, comparison of short-time data reveals that the short-time modulus needs to be reduced by two-thirds for use at five years. Therefore, a modulus of one-third the short-time modulus was used for all materials considered for this application due to the lack of short-time data.

Use of the modified strength and modulus data permits calculations to be made which will take into account the "viscoelastic" nature of plastic materials. The calculations below were performed for every material considered.

$$\text{Exterior dimension} = 5' \times 8' \times 8\ 1/2'$$

$$\text{Interior volume } V_{in} = 300 \text{ ft.}^3$$

$$\text{Skid height} = 4''$$

$$\text{Exterior volume } V_{ex} = 5 \times 8\ (8.6'' - 4'') = 5 \times 8 \times 8.167 = 326.68$$

$$\text{Wall volume } V_w = (V_{ex} - V_{in}) = 326.68 - 300 = 26.68$$

Assume top thickness of 1"

$$\text{Volume of top } V_T = 5 \times 8 \times 1/12 = 3.33 \text{ ft.}^3$$

Assume bottom thickness of 1.5"

$$\text{Volume of bottom } V_B = 5 \times 8 \times \frac{1.5}{12} = 5.00 \text{ ft.}^3$$

$$\text{Volume of four sides } V_s = V_w - V_T - V_B$$

$$V_s = 26.68 - 3.33 - 5.00$$

$$V_s = 18.35$$

$$\text{Area of sides } A_s = 8.167 \times 2\,(5 + 8) = 212.34 \text{ ft.}^2$$

$$\text{Thickness of sides } t_s = \frac{V_s}{A_s} = \frac{18.35}{212.34} = .0785 \text{ ft.} \times 12 \frac{\text{in.}}{\text{ft.}}$$

$$t_s = 1.037''$$

Weight of material in containers = 3000 lb.

Weight of containers = 500 lb.

Number of containers above bottom container = 2

Total weight on wall of bottom container = 2 x 3500 = 7000 lb.

Container perimeter length = 26 ft.

$$\text{Load/inch of perimeter} = \frac{7000 \text{ lb.}}{26 \times 12} = 22.44 \frac{\text{lb.}}{\text{in.}}$$

Based on Euler's buckling; Eqn.[1]

(1) Elements of Strength of Materials, S. Timoshenko and G. H. MacCullough, D. Van Nostrand, 3rd edition, 1949, p.293.

$$\text{Load to cause failure} = P_{cr} = \frac{\pi^2 EI}{L^2}$$

$$L = 8.167 \times 12 = 98''$$

Solve for I

$$I = \frac{P_{cr} L^2}{\pi^2 E}$$

$$E = \frac{2.9 \times 10^5}{3} = .967 \times 10^5 \text{ in.}^4 \text{ based on estimated 5-yr. modulus}$$

Use factor of safety of 1.5 will give

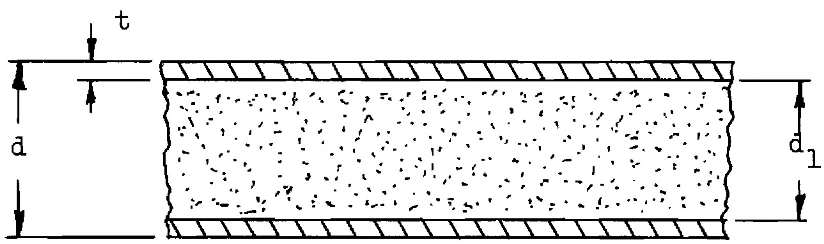
$$P_{cr} = 1.5 \times 22.44$$

$$P_{cr} = 33.66$$

$$I = \frac{33.66 \times (98)^2}{\pi^2 \; .967 \times 10^5}$$

$$I = .3391 \text{ in.}^4$$

For cases where face sheets on each side of core are of equal thickness as shown below, the moment equation reduces to:



$$I = \frac{d^3 - d_1{}^3}{12} =$$

$$d_1{}^3 = d^3 - 12I$$

$$d_1 = \sqrt[3]{d^3 - 12I}$$

$$d_1 = \sqrt[3]{(1.037)^3 - 12 \times .3391}$$

$$d_1 = \sqrt[3]{-2.95}$$

This answer says that d_1 must be less than 0 for the wall to be stable, i.e., the face sheet together must be greater than 1.037 inches thick. If the above calculation is repeated using the materials used in the Poly-Con containers, the results are as follows:

$$E = \frac{15 \times 10^5}{3} = 5 \times 10^5 \text{ in.}^4 \text{ based on estimated 5-yr. modulus}$$

Using a factor of safety of 1.5 will again give

$$P_{cr} = 1.5 \times 22.44$$

$$P_{cr} = 33.66$$

$$I = \frac{33.66\ (98)^2}{\pi^2\ 5 \times 10^5}$$

$$I = 0.656 \text{ in.}^4$$

$$d_1 = \sqrt[3]{(1.037)^3 - 12 \text{ x } .0656} = \sqrt[3]{1.115 - .787}$$

$$d_1 = \sqrt[3]{.3278}$$

$$d_1 = .6895 \text{ in.}$$

$$2t = d - d_1 = 1.037 - .6895$$

$$2t = .3475 \text{ in.}$$

$$t = .1737 \text{ in.}$$

This would seem feasible until the weight of the container is calculated. The weight of the glass reinforced polyester used in the calculation above is 112 lb./ft.^{3}.

$$\text{Container weight} = \{.1737\ [(8.5 \text{ x } 5 + 8.5 \text{ x } 8 + 8 \text{ x } 5)\ 2]\ 2\}\ 112 \text{ lb./ft.}^3$$

$$= (.1737 \text{ x } 602 \text{ x } 1/12)\ 112 \text{ lb.}$$

$$= 8.71 \text{ ft.}^3 \text{ x } 112 \text{ lb./ft.}^3$$

$$\text{Container weight} = 975.52 \text{ lb.}$$

This weight is considèrably beyond a reasonable weight. Even if this were considered a reasonable weight, several assumptions have been made that would cause additional increases in this weight. It was assumed that the door was an integral part of the container and would carry its share of the load. In practice this is very difficult to attain and still have a removable door. A rather rigid and therefore heavy framework would have to be built around the door, thus increasing the weight even further.

Similar calculations were performed for all combinations of materials considered. Similar results were obtained for every case except with the fiberglas coated plywood. The plywood container also had a metal framework which required a three dimensional rigid frame analysis which requires an iterative approach and is better handled with a computer program. That analysis is not shown here because of this container having been previously eliminated.

APPENDIX II

APPENDIX II

COST ANALYSIS OF PLASTIC CONTAINERS

The method of arriving at estimated production cost varied quite widely between the different types of construction. All companies were reluctant to give firm estimates without a good chance of obtaining a development contract. For this reason, each type container is shown separately.

(A) ABS Face Sheets with Urethane Foam Core. Cost estimates of both Marbon Chemical Company and the Uniroyal Corporation were under \$400. Since these companies are specialists with these materials and have extensive experience in fabricating large components, their estimates are probably quite accurate.

(B) Polyester-Fiberglas Sheets with Urethane Foam Core. This estimate was arrived at by using a cost figure of $\$1.50/\text{ft.}^2$ obtained from Lunn Laminates as the probable cost of flat sheets. This figure multiplied times known surface area and added to estimated assembly cost gave a rough estimate.

(C) Cast ABS Foam. This is an estimated cost figure supplied by Marbon Chemical, the supplier of the material.

(D) Cast Urethane Foam with Sprayed Polyester-Fiberglas. We were unable to get any company to give an estimated cost for this container because most felt the container would be too crude. We estimated cost by scaling down the cost of prefabricated sheet container (B).

(E) Dynakore Composite. Again this is an estimated cost figure arrived at through talks with Marbon Chemical. It may be somewhat questionable because Marbon does not produce the material at the present time.

(F) Rotationally Molded Composite. This estimate is somewhat dependent upon the material used but should be less for a given material when produced in large quantities due to reduction in labor and the automatic nature of the process.

(G) Poly-Con Industries Composite Container. This estimate is based on the costs obtained for the prefabricated container (B) with an additional increase due to the mold cost and time required in the mold. The exact nature of their process is not known but reasonable estimates can be made from the pictures and the sample I have.

APPENDIX III

APPENDIX III

WEIGHT ANALYSIS OF PLASTIC CONTAINERS

(NON-STACKED VERSION)

Once it was determined that stacking plastic containers is not within the present state of the art and that containers inserted into shelves look practical, container weights were dependent upon characteristics which were on hand or could be obtained.

Interior and exterior sheet thicknesses were chosen on the basis of impact resistance, strength, weight, and cost. Since calculations were basically the same for all containers, only the calculations for the ABS Face Sheet-Urethane Foam Core Container are shown.

1. Use .062" inner ABS sheet thickness
2. Use .093" outer ABS sheet thickness
3. Have total wall thickness of 1.037"

$$\text{Surface area} = 2(8.5 \times 5 + 8.5 \times 8 + 8 \times 5)$$

$$= 301 \text{ ft.}^2$$

$$\text{Volume of ABS} = (.062 + .093)\ (300 \text{ ft.}^2)\ 144 \text{ in.}^2/\text{ft.}^2$$

$$= 6696 \text{ in.}^3$$

$$\text{Weight of ABS} = \frac{\text{Volume of ABS}}{23 \text{ in.}^3/\text{lb.}} = \frac{6696}{23}$$

$$= 291.1 \text{ lb.}$$

$$\text{Volume of urethane foam} = \frac{(1.037 - .155)}{12} 301$$

$$= 22.1 \text{ ft.}^3$$

$$\text{Weight of urethane foam} = \text{volume x } 3.6 \text{ lb./ft.}^3$$

$$= 79.56$$

$$\text{Total weight of materials} = 291.1 + 79.56$$

$$= 370.66 \text{ lb.}$$

This weight will obviously be increased slightly by strapping attachments, latches, etc. In this way we arrived at a weight estimate of approximately 400 pounds for this container. This figure can obviously be refined considerably should it be decided to proceed with prototypes, but it is doubtful the figure will change to any extent.